ERDC SR-17-4

Engineer Research and Development Center

US Army Corps of Engineers®

Engineer Research and Development Center

ERDC

INNOVATIVE SOLUTIONS for a safer, better world

Firing Range Contaminants and Climate Change Tool

Spreadsheet User Instructions

Catherine Fox-Lent, Dayton C. Marchese, Christy M. Foran, and Michelle E. Swearingen

September 2017

Impacts due to Contaminant Concentration

Rate of Return (%)	2

	Concentrations for Climate Scenario 1 (mg/kg soi Error =								20%	Concentrations for Cl		
	Likelihood of Occurrence =								50%			
Years since present	No Action	Closure with No Remediation (Natural	Offsite landfilling	Screening	Screening and HCl leaching	Offsite disposal	Stabilization with phosphate amendment	Onsite rebuilding	Offsite rebuilding	No Action	Closure with No Remediation (Natural	Offsite landfilling
0	50	50	50	50	50	50	50	50	50	50	50	50
1	98	98	98	98	98	98	98	0	0	148	148	148
2	145	145	145	145	145	145	145	0	0	245	245	245
3	193	193	193	193	193	193	193	0	0	343	343	343
4	240	240	240	240	240	240	240	0	0	440	440	440
5	288	288	288	288	288	288	288	0	0	538	300	0
6	335	335	335	335	335	335	335	0	0	635	398	98
7	383	383	383	383	383	383	383	0	0	733	495	195
8	430	430	430	430	430	430	430	0	0	830	300	293
9	478	300	0	75	50	0	150	0	0	928	398	390
10	525	348	48	123	98	48	198	0	0	1025	495	488
11	573	395	95	170	145	95	245	0	0	1123	300	0
12	620	443	143	218	193	143	293	0	0	1220	398	98
13	668	300	190	265	240	190	340	0	0	1318	495	195
14	715	348	238	313	288	238	388	0	0	1415	300	293
15	763	395	285	360	335	285	435	0	0	1513	398	390
16	810	443	333	408	383	333	150	0	0	1610	495	488
17	858	300	380	75	430	380	198	0	0	1708	300	0
18	905	348	428	123	50	428	245	0	0	1805	398	98
19	953	395	0	170	98	0	293	0	0	1903	495	195
20	1000	443	48	218	145	48	340	0	0	2000	300	293

ERDC SR-17-4
September 2017

Firing Range Contaminants and Climate Change Tool

Spreadsheet User Instructions

Catherine Fox-Lent, Dayton C. Marchese, and Christy M. Foran

Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Hall Ferry Road
Vicksburg, MS 39180-6199

Michelle E. Swearingen

Construction Engineering Research Laboratory
U.S. Army Engineer Research and Development Center
2902 Newmark Drive
Champaign, IL 61822

Final report

Prepared for Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA(ALT))
103 Army Pentagon
Washington, DC 20314-1000

Under Research, Development, Test and Evaluate (RDTE) Program Element 622720A896, “Army Environmental Quality Technology,”
Project 2DC5L9, “Firing Range Capacity”

Abstract

The U.S. Army must maintain hundreds of thousands of acres as firing ranges for soldiers' mission readiness. The Army also is required to monitor and remediate environmental contaminants from training activities that are conducted on those ranges as a part of AR 350-19, the Sustainable Ranges Program. Climate changes are likely to cause an increase in the frequency and intensity of temperature and precipitation anomalies, and there are likely to be related impacts to the contaminants that accumulate in firing ranges. Range managers need a tool to adopt appropriate remediation strategies in the face of these changes. The Risk and Decision Science Group of the Engineering Research and Development Center's Environmental Laboratory developed a climate and range evaluation spreadsheet tool (Climate_Change_Range.xlsx) to evaluate a suite of contaminant management alternatives for military firing ranges, based on remediation cost and duration. This instructional document was subsequently developed to accompany that tool. Army range managers can now use the tool and this instructional guide as an aid to long-term range planning in the face of climate changes.

Contents

List of Figures

Figures

Preface

This study was conducted for Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology, ASA(ALT) under Research, Development, Test and Evaluate (RDTE) Program Element 622720A896, "Army Environmental Quality Technology," Project 2DC5L9, "Firing Range Capacity." The technical monitor was Mr. Alan B. Anderson, CEERD-CZT.

The work was performed by the Risk and Decision Science Team of the Environmental Risk Assessment Branch (EPR) of the Environmental Processes Division, U.S. Army Engineer Research and Development Center, Environmental Laboratory (ERDC-EL). At the time of publication, Dr. William Nelson was Chief, CEERD-EPR; Mr. Warren Lorenz was Branch Chief, CEERD-EP; and Dr. Elizabeth Ferguson, CEERD-EM-J was the Technical Director for Environmental Quality and Installations. The Deputy Director of ERDC-EL was Dr. Jack E. Davis, and the Director was Dr. Beth Fleming.

Work was supervised and contributed to by the Ecological Processes Branch (CNN) of the Installations Division (CN), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, Dr. Chris C. Rewerts was Chief, CEERD-CNN; Ms. Michelle J. Hanson was Chief, CEERD-CN; and Mr. Alan B. Anderson, CEERD-CZT, was the Technical Director for Sustainable Ranges and Lands. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti, and the Director was Dr. Ilker Adiguzel.

COL Bryan S. Green was the Commander of ERDC, and Dr. David W. Pittman was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

1.1 Background

Executive Order (EO) 13514, "Federal Leadership in Environmental, Energy, and Economic Performance" (White House 2009) declares that all federal departments and agencies are required to evaluate climate change risks and vulnerabilities, to manage the short- and long-term effects of climate change on the agency's mission and operations, and to include an adaptation planning document as an appendix to each department or agency's annual Strategic Sustainability Performance Plan (SSPP). EO 13653, "Preparing the United States for the Impacts of Climate Change" (White House 2013) went further by including the following language:

> each agency shall develop or continue to develop, implement, and update comprehensive plans that integrate consideration of climate change into agency operations and overall mission objectives and submit those plans to CEQ (Council on Environmental Quality) and OMB (Office of Management and Budget) for review.

The Department of Defense (DoD) recognizes the need for a strategic approach to the challenges posed by global climate change, including potential impacts to missions, built infrastructure, and natural resources on DoD installations. EOs, the Council on Environmental Quality (CEQ), and the Climate Change Adaptation Work Force prompted DoD elements to enact climate change policy guidance. For the DoD, this guidance was reflected in its 2010 Quadrennial Defense Review (QDR), which required that climate change be taken seriously and directly considered in long-term Army planning. The QDR, the principal means by which the National Military Strategy (NMS) is translated into new policies and initiatives, states that "The Department must complete a comprehensive assessment of all installations to assess the potential impacts of climate change on its missions and adapt as required" (DoD 2010a).

To address the QDR's call for assessment of climate change impacts, the DoD's SSPP (DoD 2010b) defined the need to integrate climate change considerations into existing processes by using robust decision-making approaches based on the best available science. In the *Department of Defense 2014 Climate Change Adaptation Roadmap*, the Army recognized that climate change interacts with stressors that it already considers and manages (DoD 2014). In the 2013 *Report to Congress on Sustainable Ranges* (DoD 2013), the Army reported progress toward fulfilling this policy. The Army's approach is to integrate climate change issues into existing processes instead of considering climate change as a separate decision-making process. The DoD also intends to fully integrate climate change considerations into its extant policies, planning, practices, and programs. This integration was described in the *Department of Defense 2014 Climate Change Adaptation Roadmap,* which refers to DoD's deep experience in planning for uncertain futures and directs the DoD Senior Sustainability Council (SSC) to establish policies and guidance for conducting consistent climate change vulnerability assessments across all DoD components (DoD 2014). In addition, *The President's Climate Action Plan* reemphasized the development of tools for more effective climate-relevant decision making (Executive Office 2013).

The Office of the Assistant Secretary of the Army for Installations, Energy, and Environment (OASA[IE&E]) has the lead responsibility for integrating climate change into Army planning processes. This responsibility is documented in the *Army Campaign Plan* (U.S. Army 2011) as Objective 2-7 "Adapt/Execute Climate Strategies." In FY12, OASA(IE&E) tasked the U.S. Army Engineer Research and Development Center (ERDC) with developing an adaptation planning framework that is consistent with CEQ and the goals of the *Department of Defense 2014 Climate Change Adaptation Roadmap* to integrate climate change planning in existing Army installation planning processes. ERDC's efforts considered five major Army installation planning processes including the following: Installation Strategic Plan, Installation Master Plan, Installation Range Complex Master Plan, Installation Integrated Natural Resource Management Plan (INRMP), and Installation Critical Infrastructure Risk Management Plan (ICRMP). This effort did not address Army enterprise planning processes including the Base Closure and Realignment Commission (BRAC), stationing decisions, and acquisitions. The Army currently lacks approaches and tools to incorporate climate change into these types of enterprise-wide decision processes. This work addresses that deficiency.

The Army requirement to consider the impact of climate on long-term enterprise-scale basing and stationing decisions directly results from the fact that weather is inherently intertwined with the Army's ability to successfully complete required training and testing missions, and to perform operation and maintenance (O&M) of both built and natural infrastructure. Future weather, as affected by climate change, will change in short-, mid-, and long-term time scales. Thus, future weather changes will be reflected not only in long-term trends, but also in the variability and frequency of extreme weather events. There is a need to support the planning decision process and its associated assessments of enterprise systems and installation functions with regard to their vulnerabilities to future weather impacts.

Movement of contaminants from live-fire training activities is strongly influenced by variable soil properties and moisture content. These contaminants need to be remediated appropriately to comply with environmental regulations, including Army Regulation (AR) 350-19, the Army Sustainable Ranges Program (U.S. Army 2005). Climate change is causing an increase in the frequency and intensity of temperature and precipitation anomalies across the United States and the world. These changes in meteorological conditions will likely lead to changes in the fate and transport of contaminants on military firing ranges (Pichtel 2012). Of importance to range managers is the cost of remediating or removing contaminated soil, particularly the variation in cost due to uncertain future climates. These cost variations manifest from the differing management strategies, remediation efficiencies, remediation durations, and required frequency of management action.

1.2 Objective

Comparing the costs associated with alternative courses of action for maintaining military capacity under climate change is a critical factor in mission-based military decision making. The clean-up costs associated with climate effects could be incurred in two ways. First, a more expensive regime of best management practices (BMPs) may be selected as a result of climate-induced impacts. Second, range closure costs with associated environmental remediation may be incurred if training infrastructure is moved due to climate impacts.

The objective of developing the Firing Range Contaminants and Climate Change spreadsheet was to provide a tool that can help assess the cost of range management strategies for various potential climate futures.* Within this tool, firing range managers will utilize inputs from soil remediation experts, climatologists, and fate and transport modelers to execute the spreadsheet calculations. The results are intended to inform decisions about range cleanup by visualizing temporal distribution of costs under different climate futures.

1.3 Methodology

Inputs to the spreadsheet's development are range characteristics, management alternative cost and time estimates, and expected contaminant concentrations in the soil. The cost incurred from developing (or redeveloping) a capacity, the costs associated with closing and remediating the current facility, and the transition costs should be specified. These three specific costs should be researched and used as inputs. The model then uses these inputs to calculate and visualize the potential loss of range availability and the potential costs of remediation. Results from the evaluation tool include net present value (NPV) of adopting each management alternative for each climate scenario, as well as contaminant management cost during each year of operation. Uncertainty is built into the model in the form of NPV error estimation, and the model accounts for the confidence of expected contaminant concentration and climate projections.

1.4 Scope

This tool was designed to serve the needs of multiple types of users, as listed below:

- Range managers have a direct stake in the cost of implementing sediment remediation and removal strategies, and they can use this tool to justify a choice or change to the range remediation plan.
- Remediation specialists can benefit from using this tool to better convey the costs of remediation to range managers, which can lead to future business development.
- Scientific community members can use this tool to better understand the impacts of climate change on contaminants in firing ranges.

---

* The spreadsheet tool is available for download at http://dx.doi.org/10.21079/11681/24336. This permanent link is a service of ERDC Library's Knowledge Core.

2 Spreadsheet Tool Design and Use

As stated in Section 1.2, the Firing Range Contaminants and Climate Change spreadsheet was developed as a tool to help assess the cost of range management strategies for various potential climate futures.* The subsections of this chapter give instructions for using that spreadsheet tool.

2.1 "Instructions" tab

The first tab of the spreadsheet contains two objects: (1) the user instructions (as described below) and (2) a PowerPoint presentation of examples. When using the spreadsheet, double click on the items to gain access.

2.2 "Cleanup" tab

The "Cleanup" tab of the spreadsheet contains inputs and calculations related to the cost of performing remediation or the removal of contaminated range soils. At the top of this tab is a user input cell (marked by yellow) for "Cleanup Soil Mass" (Figure 1). This mass should be estimated by a remediation professional familiar with the firing range to be considered. Also at the top of this tab is a user input cell for "Cost per Training Day Lost"—the net cost associated with not operating the range for a single day. This cost may include the cost of sending soldiers to another installation for training or to an alternative training range. To have this cell's input equal the net cost, the range's normal operational cost (that is being *saved* by not training) should be subtracted from the cost *incurred* by not training on the normal range). This net cost should be estimated or calculated by the range manager. Figure 1 shows an example of the "Cleanup" tab, including all user inputs.

* The spreadsheet tool is available for download at http://dx.doi.org/10.21079/11681/24336. This permanent link is a service of ERDC Library's Knowledge Core.

Figure 1. Example of the “Cleanup” tab in Climate_Change_Range.xlsx. The bright yellow cells represent user inputs that can vary, depending on the specific range.

Thresholds and Costs of Action

Cleanup Soil Mass (tons)	10000
Cost per Training Day Lost	$1,000.00

Management Action	Threshold (mg/kg soil)	Target (mg/kg soil)	Cost per ton of Soil	Treatment Duration (Days)	Remediation/Rebuilding One Time Cost
Temporary Closure with No Remediation (Natural Recovery)	400	300	$0.00	350	$350,000.00
Temporary Closure with Remediation (Different Methods)					
Offsite landfilling	400	0	$300.00	10	$3,010,000.00
Screening	400	75	$58.95	75	$664,500.00
Screening and HCl leaching	400	50	$170.00	45	$1,745,000.00
Offsite disposal	400	0	$235.00	25	$2,375,000.00
Stabilization with phosphate amendment	400	150	$21.26	100	$312,600.00
Permanent Closure with Rebuilding (Cost of Current Cleanup and New Range)					
Onsite rebuilding					$0.00
Offsite rebuilding					$0.00

2.2.1 “Management Action” column

The first column in this tab is the “Management Action” column, below which is listed each strategy to be considered for management action. These potential management actions should be elicited from remediation experts and provided as options from which range managers can choose (USEPA [U.S. Environmental Protection Agency] 2005). Only the management strategies in rows with populated yellow cells will be evaluated by the spreadsheet tool. The tool is pre-populated with five management actions commonly considered in range remediation. However, those options can be renamed and repopulated, or additional management strategies can be added.

2.2.2 “Threshold” column

The “Threshold” column holds values of the contaminant concentration in the soil for which remediation is required. In some cases, this concentration may be a single value that is specified through environmental regulations (e.g., Figure 1). This threshold may vary from installation to installation depending on the specified contaminant, state regulations, proximity to groundwater, nearby wildlife, etc. Range managers and remediation specialists should be familiar with this value or set of values (USEPA 2005). If the value is unknown, however, users should consult a local environmental compliance agency.

2.2.3 "Target" column

The "Target" column specifies the contaminant concentration in the soil that results from a one-time implementation of each remediation/management action. These values are likely to vary between management actions and contaminants of interest. For example, off-site landfilling of soil may require removal of all contaminated soil from the range, leaving a target contaminant concentration of 0 mg/kg soil. In contrast, screening the soil for larger solid particles may remove only 75% of the contaminant by mass. The values in this column should be included in any work estimates from remediation specialists (USEPA 2005). One exception to this remediation specialist elicitation is the "Natural Recovery" row. In this row, the target concentration would depend on: (a) the initial conditions, (b) the hydrogeological properties of the range, and (c) the duration of recovery. The combinations of "Treatment Duration" and "Target" for natural recovery in a specific range can be found by using fate and transport models, such as the MODFLOW* produced by the United States Geological Service (USGS) or HYDRUS 2D/3D† produced by PC-Progress. Further detail about fate and transport finite-difference models is provided in Section 3.2.1.2.2.

2.2.4 "Cost per ton of Soil" column

The "Cost per ton of Soil" column is populated by the user based on estimates from remediation specialists. These values will vary based on range properties, contaminant of interest, and the agency or company performing the remediation (Dermatas et al. 2006). The cost per ton of soil should include the *total* cost, including labor, equipment, disposal, transportation, etc. In the absence of direct input from remediation experts, these values can be estimated by range managers, based on previous remediation/removal actions at similar ranges.

* USGS's modular hydrodynamic model available for download from https://water.usgs.gov/ogw/modflow/ supporting groundwater/surface-water systems, solute transport, variable-density flow (including saltwater), aquifer-system compaction and land subsidence, and parameter estimation.

† Commercial software package for modeling water, heat, and solute movement in two- and three-dimensional variably saturated media. Package information available at: https://www.pc-progress.com/en/Default.aspx?hydrus-3d.

2.2.5 "Treatment Duration" column

The "Treatment Duration" column includes estimates for how many days the range will be closed due to remediation or removal of soils. This is used to calculate the cost to the range due to lost training days. This column is used in conjunction with the "Cost per Training Day Lost" value, and the cost may be associated with sending soldiers to other locations to train.

The "Remediation/Rebuilding One Time Cost" column is calculated based on the cost of management action and the cost due to non-operation. This column requires no user inputs, and is used in the "Impacts" tab. These costs are the total costs that the range incurs each time the remediation/removal management action is taken.

2.3 "Impacts" tab

This tab includes both inputs to and primary results from the spreadsheet tool.

2.3.1 Inputs

The first input cell is the "Rate of Return," which is a percentage that describes the annual discount rate. This value is used to calculate the NPV, and it should be chosen by range managers. Figure 2 shows the location of this input, and also a subset of the other inputs in the spreadsheet's "Impacts" tab.

Figure 2. Example of the "Impacts" tab in Climate_Change_Range.xlsx. Yellow cells are user inputs. Note that the dataset that is cut off on the right side of the figure indicates that more than one climate scenario is being assessed.

Impacts due to Contaminant Concentration

Rate of Return (%)	2

	Concentrations for Climate Scenario 1 (mg/kg soiError =								20%	Concentrations for Cl		
	Likelihood of Occurrence =								50%			
Years since present	No Action	Closure with No Remediation (Natural	Offsite landfilling	Screening	Screening and HCl leaching	Offsite disposal	Stabilization with phosphate amendment	Onsite rebuilding	Offsite rebuilding	No Action	Closure with No Remediation (Natural	Offsite landfilling
0	50	50	50	50	50	50	50	50	50	50	50	50
1	98	98	98	98	98	98	98	0	0	148	148	148
2	145	145	145	145	145	145	145	0	0	245	245	245
3	193	193	193	193	193	193	193	0	0	343	343	343
4	240	240	240	240	240	240	240	0	0	440	440	440
5	288	288	288	288	288	288	288	0	0	538	300	0
6	335	335	335	335	335	335	335	0	0	635	398	98
7	383	383	383	383	383	383	383	0	0	733	495	195
8	430	430	430	430	430	430	430	0	0	830	300	293
9	478	300	0	75	50	0	150	0	0	928	398	390
10	525	348	48	123	98	48	198	0	0	1025	495	488
11	573	395	95	170	145	95	245	0	0	1123	300	0
12	620	443	143	218	193	143	293	0	0	1220	398	98
13	668	300	190	265	240	190	340	0	0	1318	495	195
14	715	348	238	313	288	238	388	0	0	1415	300	293
15	763	395	285	360	335	285	435	0	0	1513	398	390
16	810	443	333	408	383	333	150	0	0	1610	495	488
17	858	300	380	75	430	380	198	0	0	1708	300	0
18	905	348	428	123	50	428	245	0	0	1805	398	98
19	953	395	0	170	98	0	293	0	0	1903	495	195
20	1000	443	48	218	145	48	340	0	0	2000	300	293

2.3.1.1 "Years since Present" column

At the far left of this tab is the "Years since Present" column. In this column, the user will input the operation period (in years or another time unit) for which the tool will be assessing the range operation. This temporal discretization should not be finer than the temporal discretization in the climate model used to estimate the "No Action" contaminant concentration described below.

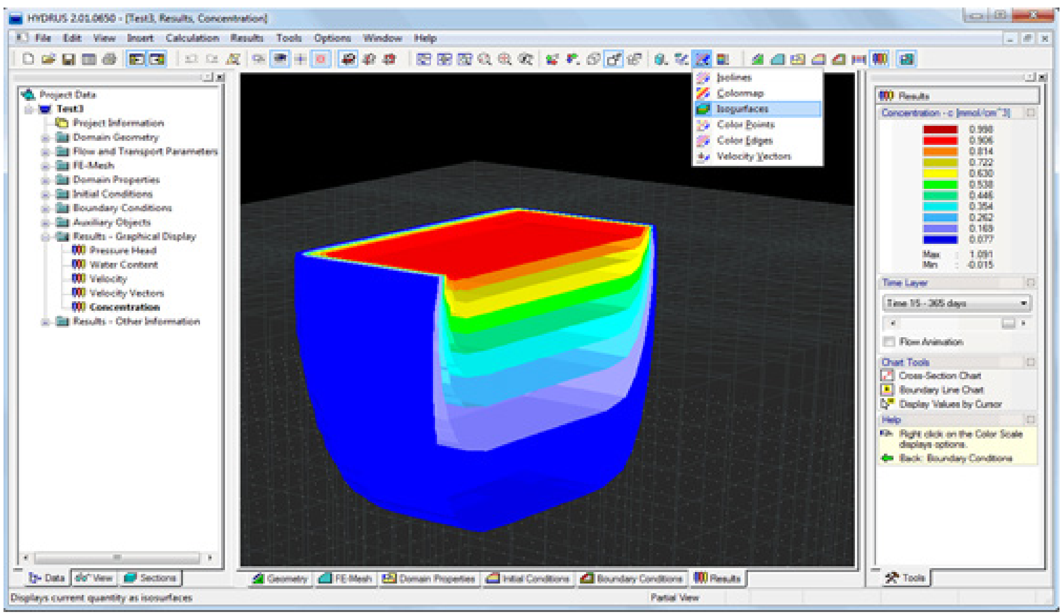
2.3.1.2 "Concentrations for Climate Scenario 1" section's data

The "Concentrations for Climate Scenario 1" data table (seen in Figure 2) holds the contaminant concentration information for a given range location and for the various management strategies detailed in the "Cleanup" tab (Section 2.2). Users should ensure that there is one of these data tables for each of the climate scenarios being compared.

2.3.1.2.1 "No Action" column

On the left side of this table is the "No Action" column, which requires user inputs. These inputs are a time series of expected contaminant concentrations in the rage given no remediation action is taken over the selected operation period. To populate this column, the user (or a hydrogeologist) would use a fate and transport model to simulate the movement of contaminants from bullets and shot on the surface of the range into the underlying soil (Simunek et al. 2012; Harbaugh 2013). As previously mentioned, MODFLOW and HYDRUS 2D/3D are examples of finite-difference fate and transport models (Simunek et al. 2012; Harbaugh 2013). Figure 3 shows an example of MODFLOW being used to simulate subsurface contaminant transport.

Figure 3. Example of contamination concentration modeling in HYDRUS. This figure was taken from the PC- Progress website at: http://www.groundwatersoftware.com/hydrus.htm.



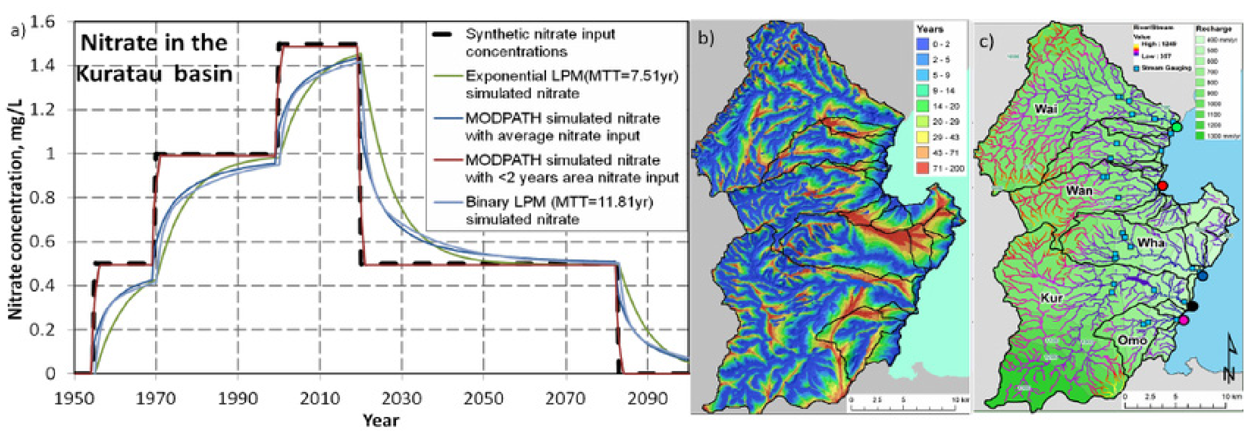
2.3.1.2.2 Discussion of fate and transport model inputs

Inputs to fate and transport models include physical range properties (size, porosity, hydraulic conductivity, volumetric water content, etc.), operational aspects such as the flux of contaminant to the soil surface from weapons discharge and surficial removal of solid contaminants, and environmental parameters (e.g., temperature and infiltration). Other inputs are the temporal specifications (i.e., over how many months/years should the model operate and in what intervals are results calculated).

The different climate scenarios impact the results of fate and transport models primarily by varying environmental parameters. Generally, a warmer and wetter climate will result in a greater flux of contaminants from the soil surface to the underlying soil column (Dermatas et al. 2006). This is because a warmer climate yields warmer soil water, which contributes to a greater hydraulic conductivity and increased infiltration of contaminated surface water (Whitacre, Ware, and Gunther 2008). Additionally, both dissolution and sorption increase with higher temperatures, causing a greater flux of contaminants from the surface solids to the soil column (Whitacre, Ware, and Gunther 2008). One notable exception to this relationship is for steeply sloped ranges, on which an increase in precipitation may result in a greater surface flux of contaminants off the range towards a lower elevation.

Among the outputs of the fate and transport models are time series of contaminant concentration at specified points in the domain. The domain in this case would be the affected volume of soil in the firing range. The time series of expected contaminant concentration would serve as inputs to the "No Action" column in the "Impacts" tab. The uncertainty in the contaminant load time series can be estimated using the distributions of climate projections for each climate scenario (IPCC Working Group 1 2013). The contaminant fate and transport models can be executed using a range of climate inputs to yield a range of concentration time series (Harbaugh et al. 2013). An example of a contaminant concentration time series produced by MODFLOW is shown in Figure 4.

Figure 4. Simulated nitrate concentrations in the Kurataur river basin. (This figure was simulated using MODFLOW in Gusyev et al. 2015.



The highlighted cells in the main part of the "Concentration for Climate Scenario X" data tables are calculated based on the "No Action" column in the same tab, and the "Threshold" and "Target" columns in the "Cleanup" tab. The increase in concentration in the light blue cells matches the increase in concentration in the "No Action" column. This assumes a zero-order increase (i.e., the increase in contaminant concentration is independent of current concentration), which is a common assumption in these models for lead and other contaminants such as RDX, TNT, and 2,4-DNT (Brannon and Pennington 2002; Ho 2006; Whitacre, Ware, and Gunther 2007). This assumption should be replicated in the fate and transport model by specifying a linear sorption isotherm. If a contaminant concentration exceeds the threshold concentration for a management strategy, the spreadsheet tool lowers the concentration to the associated target and the range incurs the management action cost.

2.3.1.3 "Error" and "Likelihood of Occurrence" cells

Other input cells in this tab include "Error" and "Likelihood of Occurrence." The error cell is the percentage error of the no action contaminant concentration time series. This error includes the error associated with the climate scenario and can be found within the climate model, or it can be estimated by executing regional circulation models with inputs described by probability distributions (IPCC [Intergovernmental Panel on Climate Change] Working Group 1 2013). Depending on the model used to generate the expected contaminant concentration time series, the error might take the form of a probability distribution. The spreadsheet tool could be reconfigured to accept distributions instead of a percentage error, if the user chooses. If the distributions were normal, no simulations (e.g., Monte Carlo) would be required and the resulting cost estimates would also follow a normal distribution. If the contaminant concentrations followed another probability distribution (e.g., lognormal, exponential, triangular), simulations could be built into the spreadsheet tool in the form of a macro or an add-in from external software (e.g., R[*]).

The Likelihood of Occurrence cell's input is the probability that each climate scenario will occur. The sum of all of these likelihoods should equal 1 when assessing all suggested climate models. If not all climate scenarios are being assessed, or if likelihoods of scenario occurrences are unknown, equal weights should be assigned for all evaluated climate scenarios.

*R is an open-source programming language aimed at statistical computing. The platform can be accessed at: https://www.r-project.org/.

2.3.2 Results

The graphical results of the spreadsheet tool are provided within the “Impacts” tab and below the “Concentration for Climate Scenario” data tables. These results are presented in three ways: (1) NPV by Climate Scenario and Management Action, (2) Expected Value of Management Actions, and (3) Cost per Year for each Climate Scenario (Figure 5). NPV by Climate Scenario and Management Action shows a cost comparison between different management strategies for remediating/removing contaminated soils under each of the assessed climate scenarios using the discount rate input by the user. Range managers may use this graph to choose a primary management strategy for the range. Managers may also use this graph to determine if climate change is expected to significantly change the future costs of remediation. For example, the similarity of results between Climate Scenarios 2 and 3 in Figure 5a may result in unaltered management strategies. Expected Value of Management Actions (Figure 5b) shows a comparison of management strategies, based on the distributed probabilities across climate scenarios. The expected value utilizes the “Likelihood of Occurrence” provided for each assessed climate scenario. This is useful in choosing a management strategy considering multiple future climates. The Climate Scenario Costs per Year (Figure 4c–Figure 4e) provide information about when remediation/removal of contaminated sediments is expected to occur. This information is particularly useful when planning for temporally incurring costs. For example, comparing Climate Scenarios 2 and 3 in Figure 5a we see that for Off-site Disposal, Climate Scenario 3 is expected to have a higher NPV over the 20-year assessment period. However, when looking at Figure 5d and Figure 5e, we see that Climate Scenario 2 is expected to result in an early investment (4 years from present) compared to Climate Scenario 3 (11 years from present). Range managers may take this into account if there are other building or construction plans expected for the range. These figures are also important in considering that the visualization has an arbitrary cut-off for NPV calculation at 20 years. If a remediation alternative is not triggered until year 21, the NPV would reflect no cost. However, the actual cost would be based on the necessary process and the frequency at which it needs to be repeated.

Figure 5. Results of the Climate_Change_Range.xlsx spreadsheet tool. All results were calculated assuming three independent climate scenarios: (a) NPV by climate scenario and management action, (b) NPV for weighted climate scenario, and (c)–(e) cost per year for each climate scenario.

2.3.3 Cost at time of implementation and NPV data tables

Below the results in the “Impacts” tab, there are tables that calculate the cost at the time of implementation and the NPV. Every time a concentration of contaminants is taken from the threshold to the target, a remediation/removal is expected to have occurred, and a cost is applied. This is calculated for each of the management strategies by using specifications from the “Cleanup” tab. The NPV data table converts the costs at time of implementation to an NPV by using the rate of return specified at the top of the “Impacts” tab.

2.3.4 Error bar calculations

Error bars in the graphical results are applied by executing the spreadsheet tool for time series of contaminant concentrations that are ± % Error specified in each climate scenario data table. These calculations are performed and stored in data tables hidden below the existing tables. For example, by expanding rows 32–72 in the “Impacts” tab, the error calculations of contaminant concentration are revealed (Figure 6). There are similar hidden tables below the “Cost at time of implementation” and

"NPV" data tables. To expand the assessment time used the in the tool, the user must expand the visible and hidden tables.

Figure 6. Excerpt from Climate_Change_Range.xlsx. Note that the bottom table shown in this figure is hidden in the spreadsheet and should be accessed if the user intends to alter the temporal range of application.

		Concentrations for Climate Scenario 1 (mg/kg soil)							Error =	20%		Concen
							Likelihood of Occurrence =			50%		
Years since present		No Action	Temporary Closure with No Remediation	Offsite landfilling	Screening	Screening and HCl leaching	Offsite disposal	Stabilization with phosphate amendment	Onsite rebuilding	Offsite rebuilding		No Action
0		50	50	50	50	50	50	50	50	50		50
1		98	98	98	98	98	98	98	0	0		148
2		145	145	145	145	145	145	145	0	0		245
3		193	193	193	193	193	193	193	0	0		343
4		240	240	240	240	240	240	240	0	0		440
5		288	288	288	288	288	288	288	0	0		538
6		335	335	335	335	335	335	335	0	0		635
7		383	383	383	383	383	383	383	0	0		733
8		430	430	430	430	430	430	430	0	0		830
9		478	478	478	478	478	478	478	0	0		928
10		525	525	525	525	525	525	525	0	0		1025
11		573	573	573	573	573	573	573	0	0		1123
12		620	620	620	620	620	620	620	0	0		1220
13		668	300	0	0	0	0	0	0	0		1318
14		715	348	48	48	48	48	48	0	0		1415
15		763	395	95	95	95	95	95	0	0		1513
16		810	443	143	143	143	143	143	0	0		1610
17		858	490	190	190	190	190	190	0	0		1708
18		905	538	238	238	238	238	238	0	0		1805
19		953	585	285	285	285	285	285	0	0		1903
20		1000	633	333	333	333	333	333	0	0		2000
	(+) Error	117	117.00	117.00	117.00	117.00	117.00	117.00	117.00	117.00		177
		174	174.00	174.00	174.00	174.00	174.00	174.00	0.00	0.00		294
		231	231.00	231.00	231.00	231.00	231.00	231.00	0.00	0.00		411
		288	288.00	288.00	288.00	288.00	288.00	288.00	0.00	0.00		528
		345	345.00	345.00	345.00	345.00	345.00	345.00	0.00	0.00		645
		402	402.00	402.00	402.00	402.00	402.00	402.00	0.00	0.00		762
		459	459.00	459.00	459.00	459.00	459.00	459.00	0.00	0.00		879
		516	516.00	516.00	516.00	516.00	516.00	516.00	0.00	0.00		996
		573	573.00	573.00	573.00	573.00	573.00	573.00	0.00	0.00		1113
		630	630.00	630.00	630.00	630.00	630.00	630.00	0.00	0.00		1230
		687	300.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		1347
		744	357.00	57.00	57.00	57.00	57.00	57.00	0.00	0.00		1464
		801	414.00	114.00	114.00	114.00	114.00	114.00	0.00	0.00		1581
		858	471.00	171.00	171.00	171.00	171.00	171.00	0.00	0.00		1698
		915	528.00	228.00	228.00	228.00	228.00	228.00	0.00	0.00		1815
		972	585.00	285.00	285.00	285.00	285.00	285.00	0.00	0.00		1932
		1029	642.00	342.00	342.00	342.00	342.00	342.00	0.00	0.00		2049

3 Examples

As an example of how to use the tool and the insights this calculation and visualization may provide, several examples were developed as explained below. First, a base case with several climate scenarios has been implemented to show the tool's outputs. A second example, with the higher contaminate load needed to trigger remediation and more stringent clean-up targets, shows the frequency of treatment and the NPV changes. The third example shows how the decelerated use, reflected in lower exponential addition of contaminant, drives the NPV for different alternative treatment strategies.

3.1 Base

In the base case, thresholds are all set to 400 mg/kg soil, but targets vary depending on the remediation action type (see Figure 1). Costs per ton of soil also vary, yielding a range of one-time remediation costs of $312,600 to $3.01 million for the considered remediation actions. In this same case, concentration time series are set to start at 50 mg/kg soil for each of the three climate scenarios (see Figure 2), then increase linearly to 1000 mg/kg soil for Scenario 1, increase linearly to 2000 mg/kg soil for Scenario 2, and increase exponentially with a rate constant of 0.2 for Scenario 3. This yields the results seen in Figure 5.

3.2 Adjusted thresholds and targets

By changing the thresholds and targets, the time and number of occasions when remediation action is required can be altered. Figure 7 shows these changes. These changes then lead to change in the cost results. In particular, increasing the threshold values and decreasing the target values, but keeping the treatment duration the same, will lead to a decrease in NPV and in the cost per year for the management action.

3.3 Adjusted contaminant time series

This case changes the time series of contaminant concentrations expected for Climate Scenario 3. The time series starts at 50 mg/kg soil, then increases exponentially with a rate constant of 0.15 (instead of 0.20 as in the base case). This change brings the NPV very close to equal for both Scenario 1 and Scenario 3 (Figure 8). However, Figure 8 shows the cost per year is incurred earlier in Scenario 1, due to the exponential nature of Scenario 3 and the linear behavior of Scenario 1.

Figure 7. Example inputs from Climate_Change_Range.xlsx. Changes to thresholds and targets to uniform values are shown, except for the natural recovery target.

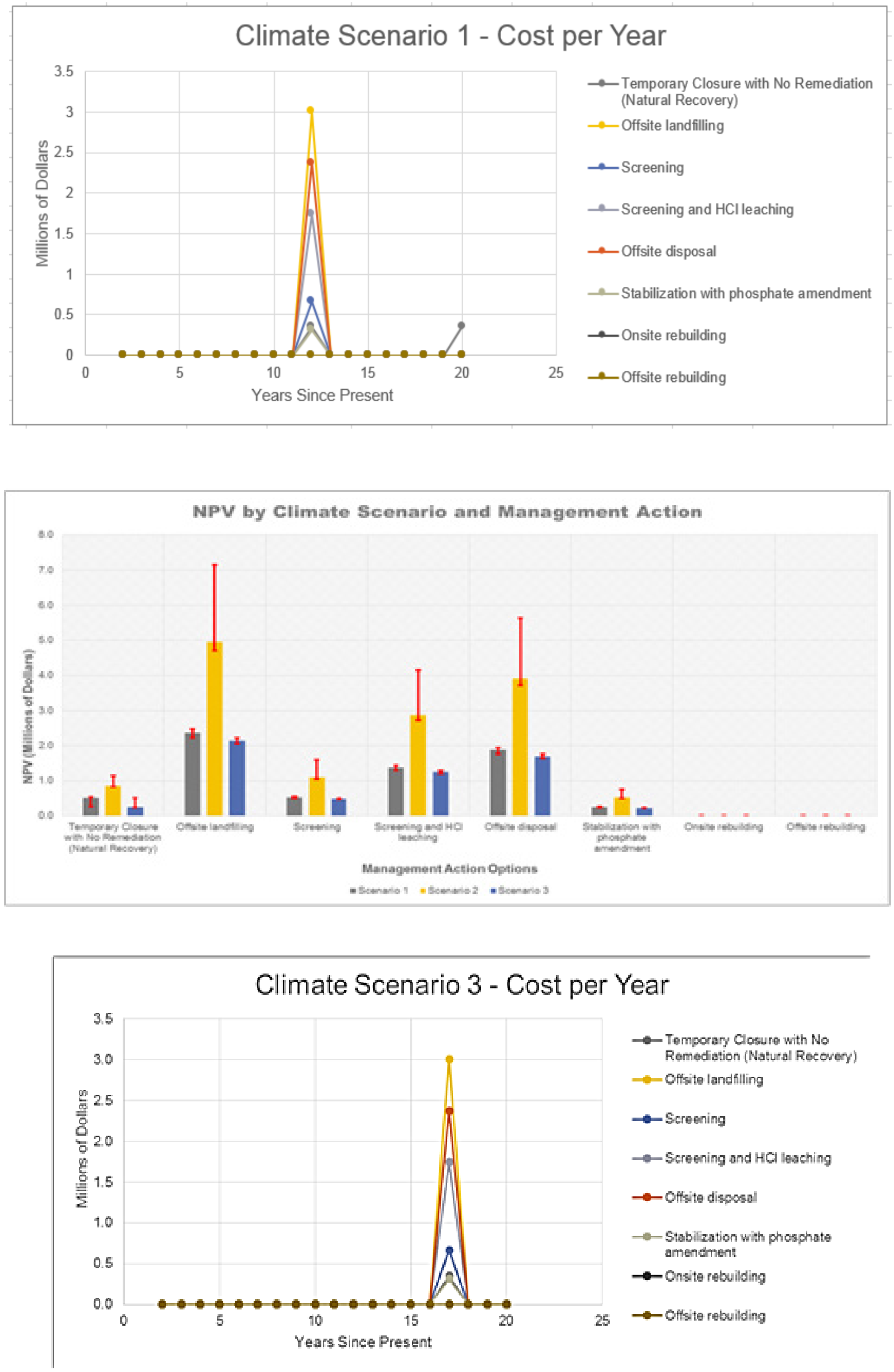
Thresholds and Costs of Action

Cleanup Soil Mass (tons)	10000	Should this be area, volume, density?
Cost per Training Day Lost	$1,000.00	

Management Action	Threshold (mg/kg soil)	Target (mg/kg soil)	Cost per ton of Soil	Treatment Duration (Days)	Remediation/Rebuilding One Time Cost
Temporary Closure with No Remediation (Natural Recovery)	600	300	$0.00	350	$350,000.00
Temporary Closure with Remediation (Different Methods)					
Offsite landfilling	600	0	$300.00	10	$3,010,000.00
Screening	600	0	$58.95	75	$664,500.00
Screening and HCl leaching	600	0	$170.00	45	$1,745,000.00
Offsite disposal	600	0	$235.00	25	$2,375,000.00
Stabilization with phosphate amendment	600	0	$21.26	100	$312,600.00
Permanent Closure with Rebuilding (Cost of Current Cleanup and New Range)					
Onsite rebuilding					$0.00
Offsite rebuilding					$0.00

Changes to thresholds and targets

Figure 8. Excerpt from Climate_Change_Range.xlsx. Although Climate Scenarios 1 and 3 both begin with 50 mg/kg soil and end with ~1000 mg/kg soil, there is a difference in cost per year and NPV due to the temporal behavior of the contaminant concentration inputs.



4 Summary and Recommendations

4.1 Summary

The spreadsheet tool described in this document provides a means for comparing the types, timing, and costs of contaminant remediation strategies for firing ranges under varying climate projections. This tool allows the user to examine the strategies available for a “status quo” situation (no climate change) and to project future changes in climate conditions on the situation. This comparison between current and future situations illustrates the range in expected costs (given the range of expected climate scenarios) and can help in long-term range planning. This tool can also compare remediation strategies, given a weighted climate scenario. This capability is an important part of accounting for the uncertainty in expected climate scenarios. By utilizing the cost-per-year results, range managers can make remediation decisions based on time of implementation, as well as NPV.

4.2 Recommendations

This research provides decision support, and the collection and analysis of range use and remediation information to support planning processes for training, national and regional stationing, and base realignment. Its use is intended to support long-range goals for 10–20 years in the future, while also accounting for the possible future consequences of climate change. Effective planning is critical to balancing the operational, facility, and environmental requirements with political sensitivities involved in developing new training, use, and stationing decisions. It is intended that the tool be used by Installation Management Command and Army Environmental Command on a case-by-case basis to consider long-range planning for training and range use at installations.

4.3 Model location and point of contact

This model for risk assessment was created by the ERDC Environmental Laboratory (ERDC-EL), specifically the Risk and Decision Science Team, which is seated at the U.S. Army Corps of Engineers (USACE), New England District Office (NAE). Questions may be directed to the Risk and Decision Science Team (696 Virginia Road Concord, MA 01742-2718), point of contact (POC): Igor Linkov (Igor.Linkov@usace.army.mil).

References

Brannon, James M., and Judith C. Pennington. 2002. *Environmental Fate and Transport Process Descriptors for Explosives*. ERDC/EL TR-02-10. Vicksburg, MS: Engineer Research and Development Center-Environmental Laboratory. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA403162.

Dermatas, Dimitris, Xinde Cao, Valentina Tsaneva, Gang Shen, and Dennis G. Grubb. June 2006. "Fate and Behavior of Metal(loid) Contaminants in an Organic Matter-Rich Shooting Range Soil: Implications for Remediation." *Water, Air, & Soil Pollution: Focus* 6(1): 143–55. doi:10.1007/s11267-005-9003-4.

DoD (Department of Defense). 2010a. 2010a. *Quadrennial Defense Review (QDR) Report*. Washington, DC: DoD.

———. 2010b. *Department of Defense Strategic Sustainability Performance Plan*. Washington, DC: DoD.

———. 2012. *DoD Climate Change Adaptation Roadmap*. Washington, DC: DoD. http://www.acq.osd.mil/ie/download/green_energy/dod_sustainability/2012/Appendix%20A%20-%20DoD%20Climate%20Change%20Adaption%20Roadmap_20120918.pdf.

———. 2013. *2013 Report to Congress on Sustainable Ranges*. Washington, DC: DoD. http://www.denix.osd.mil/sri/upload/SRR2013.pdf

———. 2014. "2014 Climate Change Adaptation Roadmap." Alexandria, VA: Office of the Assistant Secretary of Defense (Energy, Installations & Environment), Environment, Safety & Occupational Health Directorate. http://www.acq.osd.mil/eie/Downloads/CCARprint_wForward_e.pdf.

Executive Office of the President. June 2013. *The President's Climate Action Plan*. Washington, DC: Executive Office of the President, https://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf.

Gusyev, Maksym A., Daniel Abrams, Uwe Morgenstern, and Mike Stewart. 2015. "Development of Nitrate Response Curves Using MODFLOW-MODPATH, MODFLOW-MT3DMS, and Lumped Parameter Model." Paper presented at "MODFLOW and More 2015: Modeling a Complex World", 31 May–03 June 2015 at Colorado School of Mines, Golden, CO. Accessed 27 September 2016 at https://www.researchgate.net/profile/Maksym_Gusyev/publication/278038514_Development_of_nitrate_response_curves_using_MODFLOW-MODPATH_MODFLOW-MT3DMS_and_lumped_parameter_model/links/55ecdcf708ae21d099c74352.pdf.

Harbaugh, Arlen W. 2013. "Modflow-2005, The U.S. Geological Survey Modular Ground-Water Model–the Ground-Water Flow Process." U.S. Geological Survey Techniques and Methods 6-A16. Washington, DC: U.S. Department of the Interior, U.S. Geological Society. http://pubs.usgs.gov/tm/2005/tm6A16/.

Ho, Yuh-Shan. 2006. "Isotherms for the Sorption of Lead onto Peat: Comparison of Linear and Non-Linear Methods." *Polish Journal of Environmental Studies* 15(1): 81–86.

IPCC (Intergovernmental Panel on Climate Change). 2013. “Climate Change 2013: The Physical Science Basis.” T.F. Stocker, D. Qin, G.-K. Plattner, M Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley, eds. Contribution of Working Group I to the *Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, U.K. and New York, NY: Cambridge University Press.

Pichtel, John. 2012. “Distribution and Fate of Military Explosives and Propellants in Soil: A Review.” *Applied and Environmental Soil Science* Vol. 2012: 1–33. doi:10.1155/2012/617236.

Simunek, J. M., Th. Van Genuchten, M. Sejna. 2011 “The HYDRUS Software Package for Simulating the Two- and Three-Dimensional Movement of Water, Heat, and Multiple Solutes in Variably-Saturated Porous Media.” Technical Manual, Version 2.0. Prague, Czech Republic: PC-PROGRESS. https://www.pc-progress.com/downloads/Pgm_Hydrus3D2/HYDRUS3D%20Technical%20Manual.pdf.

U.S. Army. 2005. “The Army Sustainable Range Program.” AR 350-19. Washington, DC: Headquarters, U.S. Army.

U.S. Army. 2011. *Army Campaign Plan*. Washington, DC: Headquarters, U.S. Army.

USEPA (U.S. Environmental Protection Agency). 2005. “Best Management Practices for Lead at Outdoor Shooting Ranges.” Manual EPA-902-B-01-001. New York, NY: USEPA Division of Enforcement and Compliance Assistance. https://www.epa.gov/lead/best-management-practices-lead-outdoor-shooting-ranges-epa-902-b-01-001-revised-june-2005.

Whitacre, D.M., George Ware, and Francis A. Gunther. 2008. *Reviews of Environmental Contamination and Toxicology,* Vol. 191. New York: Springer. http://site.ebrary.com/id/10239454.

White House, The. 5 October 2009. Federal Leadership in Environmental, Energy, and Economic Performance. Executive Order (EO) 13514. *Federal Register* 74(194):52117-52127. http://www.gpo.gov/fdsys/pkg/FR-2009-10-08/pdf/E9-24518.pdf

_________. 1 November 2013. Preparing the United States for the Impacts of Climate Change. EO 13653. *Federal Register* 78(215):66819-66824. http://www.gpo.gov/fdsys/pkg/FR-2013-11-06/pdf/2013-26785.pdf

Appendix: Instructions for Using Climate_Change_Range.xlsx

The list included here offers a description of user inputs to the spreadsheet in more detail than the cell labels allow. The user inputs here progress through the spreadsheet tabs from front to back.

Note: Bright yellow cells and subsections require user inputs

1. Cleanup
    1.1. Cleanup Soil Mass (tons)
        1.1.1. Input the mass of soil on the range that is to be remediated or removed.
        1.1.2. This could be altered to be a cleanup volume and density, or an area, depth, and density.
    1.2. Cost per Training Day Lost
        1.2.1. Input the costs associated with not operating the range for one day.
    1.3. Management Action
        1.3.1. Details the action that might be taken to address contaminated firing ranges.
        1.3.2. Category 3: Permanent Closure with Rebuilding — includes cost to remediate the range and rebuild at another location (probably not a cost-effective management strategy to adopt on most ranges).
    1.4. Threshold
        1.4.1. Input the level of contamination at which management action is required (we use units of [mg/kg soil], but that can be changed to match the contaminant load units given on tab "Impacts").
    1.5. Target
        1.5.1. Input the target concentration to which the range is being remediated.
    1.6. Cost per Ton of Soil
        1.6.1. Input the cost per ton of soil to complete action.

1.6.2. This cost is only the cost of remediation (labor, permitting, equipment, materials, etc.) and does not include cost due to loss of operation.

1.7. Treatment Duration

1.7.1. Input the number of days that the range is to be shut down due to remediation.

1.7.2. This input is for calculating the cost to the range due to lack of operation.

1.8. Remediation/Rebuilding One Time Cost

1.8.1. This is the calculated cost to perform the associated action for a single time, including remediation costs and cost due to lack of operation.

2. Impacts

2.1. Rate of Return (or Discount Rate)

2.1.1. Input the rate of return (%) for the net present value (NPV) calculation.

2.2. Concentrations for Scenarios

2.2.1. Input the No Action concentrations of contaminant for each climate change scenario.

2.2.2. This is a time series of the contaminant concentration in the range, if no remediation action were to be taken.

2.2.3. These time series should be the result of hydrological, meteorological, and contaminant fate and transport modeling for each climate change scenario being evaluated.

2.2.4. Increases in concentrations in these tables are calculated based on the "No Action" time series, with a management action taken when the concentration exceeds the threshold.

2.2.5. These calculations assume that accumulation of contaminants in the range is zero order (i.e., contaminants accumulate at a rate independent of concentration); could be confirmed/amended with further research.

2.3. Error

2.3.1. Input the percent error estimated for the No Action contaminant concentration time series.

2.3.2. This could be changed from a uniform percentage to a time-dependent percentage (e.g., over the next 5 years the concentrations have a 95% confidence and from 6–20 years the concentrations have a 75% confidence), or it could be altered to accept a distribution of expected concentrations.

2.4. Likelihood of Occurrence

2.4.1. Input the percent likelihood for each climate scenario (the likelihood that each climate scenario will occur – sum of all scenario likelihood equals 1).

2.5. NPV by Climate Scenario and Management Action

2.5.1. This graph gives the range of expected NPVs for various management actions and climate scenarios.

2.5.2. A decision maker might look at this graph and learn that for Climate Scenario 3, Stabilization with Phosphate Amendment is the least expensive management strategy to adopt.

2.5.3. This graph pulls data from the Total NPV table at the bottom of the sheet.

2.5.4. (+) and (-) Error rows apply error bars. These error bars represent the upper and lower bounds of the NPV, given that the No Action contaminant concentration time series has a percent error specified in Sec. 2c.

2.6. NPV for Weighted Climate Scenario

2.6.1. This graph is the weighed sum of 'NPV by Climate Scenario and Management Action,' using the likelihoods provided in Section 2d.

2.6.2. This graph may inform decision makers about which management action to choose without specifying a single climate scenario.

2.7. Climate Scenario Cost per Year Graphs

2.7.1. These graphs show the cost of each management action, at the time it is required. This is given in "Years Since Present" (i.e., years into the future)

2.7.2. This provides decision makers information about when management strategies need to be implemented

3. Additional Notes and Assumptions

3.1. Assume that each firing range will be subjected to a single remediation methodology throughout the modeling period (i.e., managers will choose which methodology is best over time for each range) ##Notable exception is in the last years of range lifetime. Manager might choose a cheaper and less effective method near the end of range lifetime, if no further remediation required

3.2. Note that the NPV is arbitrarily dependent on the ending year of the evaluation period. For example, if the evaluation period ends on a remediation year, the NPV will be skewed high. Whereas ending on the year before remediation is required will skew the NPV low.

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
September 2017	Final Special Report	

4. TITLE AND SUBTITLE
Firing Range Contaminants and Climate Change Tool: Spreadsheet User Instructions

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
622720 A896

6. AUTHOR(S)
Catherine Fox-Lent, Dayton C. Marchese, Christy M. Foran, and Michelle E. Swearingen

5d. PROJECT NUMBER
2DC5L9

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Engineer Research and Development Center (ERDC)
Construction Engin. Research Lab (CERL)
PO Box 9005
Champaign, IL 61826-9005

U.S. Army Engineer Research and Development Center (ERDC)
Environmental Laboratory (EL)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CERL SR-17-4

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Assistant Secretary of the Army for
Acquisition, Logistics, and Technology
103 Army Pentagon
Washington, DC 20314-1000

10. SPONSOR/MONITOR'S ACRONYM(S)
ASA(ALT)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release. Distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The U.S. Army must maintain hundreds of thousands of acres as firing ranges for soldiers' mission readiness. The Army also is required to monitor and remediate environmental contaminants from training activities that are conducted on those ranges as a part of AR 350-19, the Sustainable Ranges Program. Climate changes are likely to cause an in-crease in the frequency and intensity of temperature and precipitation anomalies, and there are likely to be related impacts to the contaminants that accumulate in firing ranges. Range managers need a tool to adopt appropriate remediation strategies in the face of these changes. The Risk and Decision Science Group of the Engineering Research and Development Center's Environmental Laboratory developed a climate and range evaluation spreadsheet tool (Climate_Change_Range.xlsx) to evaluate a suite of contaminant management alternatives for military firing ranges, based on remediation cost and duration. This instruction-al document was subsequently developed to accompany that tool. Army range managers can now use the tool and this instructional guide as an aid to long-term range planning in the face of climate changes.

15. SUBJECT TERMS
Bombing and gunnery ranges, Rifle-ranges, Pollutants, Soil pollution-- Climatic factors, Climatic changes

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)
Unclassified	Unclassified	Unclassified	UU	35	